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*Published in:*
Procedia Manufacturing

*DOI (link to publication from Publisher):*
10.1016/j.promfg.2018.12.012



*Publication date:*
2019

*Document Version*
Publisher's PDF, also known as Version of record



*Citation for published version (APA):*
Brunø, T. D., Mortensen, S., Andersen, A-L., & Nielsen, K. (2019). Learning Factory with Product Configurator for Teaching Product Family Modelling and Systems Integration. *Procedia Manufacturing*, *28*, 70-75. https://doi.org/10.1016/j.promfg.2018.12.012

Available online at www.sciencedirect.com

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Procedia Manufacturing 28 (2019) 70–75

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

International Conference on Changeable, Agile, Reconfigurable and Virtual Production

# Learning Factory with Product Configurator for Teaching Product Family Modelling and Systems Integration

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**Abstract**

This paper presents a new approach for teaching product family modelling, product configurator and systems integration in engineering masters educations as well as for teaching industry professionals. Based on a recently acquired smart production lab, containing a reconfigurable manufacturing system with a manufacturing execution system (MES), being able to produce individually configured products, a new learning approach was introduced. Previous approaches to teaching product family modelling and product configuration have focused on achieving specific individual learning objectives in desk exercises. However, in this revised approach, lab resources are increasingly being involved, which gives the students a more in-depth value chain perspective as well learning additional aspects of systems integration.



*Keywords:* Learning factory, product configuration, product family modelling

## 1. Introduction

Most industries are today reporting customer demand for increased product variety, implying that manufacturing systems must be able to change more quickly between variants. Additionally, companies experience shorter product life cycles, implying that products and product families are produced over shorter periods of time, and an increasing demand for shorter time to market [1]. Combining this with an ever-increasing international competition, manufacturing companies face great challenges in designing manufacturing systems which are at one time both efficient, able to manufacture large variety, and being able to respond to changes in market requirements, while also meeting new customer requirements for sustainability [2]. Several paradigms have been introduced in literature to address this, including the concept of the reconfigurable manufacturing system (RMS) [3]. A more generalized term

2351-9789 
10.1016/j.promfg.2018.12.012

describing a manufacturing systems ability to cope with changes is changeability [4,5], which encompasses different classes of changeability, ranging from the ability to handle smaller changes during the operation of the system (changeover-ability) to a factory's ability to handle significant changes in product, by e.g. introducing product types never produced before.

The concept of mass customization, introduced by Pine [6] in the early nineties has since then gained acceptance in various industries and is now de facto standard in most industries, stressing the need for changeable manufacturing systems. One among other important enablers of mass customization, is choice navigation, as introduced by Salvador et al. [7]. Choice navigation is often implemented using a product configurator, a software tool, which allows users to define a configuration of a product, based on predefined variety.

Recognizing these needs in industry, higher education teaching in manufacturing engineering must address these challenges, enabling engineering graduates to assist companies in establishing changeable manufacturing systems, supporting mass customization. Combining this with emerging technological trends such as Industrie 4.0 and the Industrial Internet of Things, led the department of Materials and Production at Aalborg University in Denmark to introduce a new course with the name "Flexible Manufacturing". After this course had run for two years, the department invested in a new smart production lab, containing a reconfigurable, cyber-physical manufacturing system. It was then decided to integrate the smart production lab into the "Flexible Manufacturing" course. One element in doing this was to develop a product configurator setup, which would enable the students to analyze the current product range being producible one the manufacturing system, model this, develop a product configurator, and connect this to the manufacturing system, thus being able to initiate the manufacturing of a configured product.

The objective of this paper is to describe the technical setup behind the configurator and manufacturing system integration, and how this is integrated in the course to achieve certain learning objectives. The paper first describes the system which students work on, by first introducing the actual manufacturing system, it's structure and characteristics, as well as the products which may be produced on the system. Then the configurator solution is introduced, and how this is integrated with the manufacturing system. This is followed by a description of the learning approach related to the product configurator and the manufacturing system, including a general context of the course.

## 2. System description

### 2.1. Cyber-physical production system and MES setup

The AAU learning factory is an interdisciplinary platform for teaching and research at Aalborg University as described by Madsen & Møller [8]. The AAU learning factory is illustrated in figure 1, and is based on FESTO Cyber-Physical didactic learning factory, classified as narrow sense of learning factory [9]. Over time the AAU learning factory has been expanded with additional technologies (E.g. collaborative robots and Automated Guided Vehicles) and digital twins to obtain also a broader sense of learning factory as illustrated by Mortensen & Madsen [10]. The AAU learning factory utilizes modulization of process and resources, each with various scope of flexibility, from simple conveyer modules with dedicated process modules attached to flexible collaborative robots. The system has two main categories of modules: Conveyer modules and process(resources) modules. The six linear, one T-junction, and one sidetrack conveyer modules can be combine sequential, due to the standardize interfaces. Each conveyer module has two place holders for attaching process modules.

The processes in the AAU learning factory are: 2 different feeders, drilling, assembly, quality check, re-work station, and finally assembly. The modulization of processes and resources ensures 9 million different configurations of the manufacturing system and thereby establishes the foundation for mass customization and the identification as a changeable manufacturing system.

Fig. 1 AAU Learning Factory

The AAU learning factory uses RFID to track the current state of the product in the system, thus one-of-a-kind production can be obtained. The mass customized product is an assembly task of a dummy cellphone with simulated process, such as drilling. The dummy phone consists of a product house, in three different colors, with the options of adding, a circuit board, number and placement of fuses and drilled holes, and a top cover also available in three colors. The AAU learning factory can in is currents state handle 816 variants. The variant of the product is chosen from a list of various products in the manufacturing executing system (MES). However, the MES have some limitation in configurate the product. Each product variant is hard-coded with the sequence of operations, order number, and allocated resources, which leads to only 11 product variants being present in the MES database.

### *2.2. Development of product configurator solution*

The product configurator solution is based on the configurator software "Configit Model" offered by the company Configit [11]. "Configit Model" provides an easy to use modelling interface, which allows users with a short introduction to start modelling product variety. Compiling the product model in the modelling software enables running the runtime configurator, which starts a local web server, running a web application containing the actual configurator. In this configurator, users would be able to configure the product using the variables defined in the modelling environment. The modelling tool allows for defining constraints in the product family model, to delimit the choices the users can make in the final configurator, based on previous choices. As an example, the product manufactured by the manufacturing system may only be configured with fuses, if a printed circuit board is chosen.

Once a configuration is made by making selections for the variables, the configuration can be saved. This produces an XML file, which is structured according to the product model defined in the modelling tool. Using this XML file, it is possible to extract all variables and their vales in the configuration, given the variable name is known.

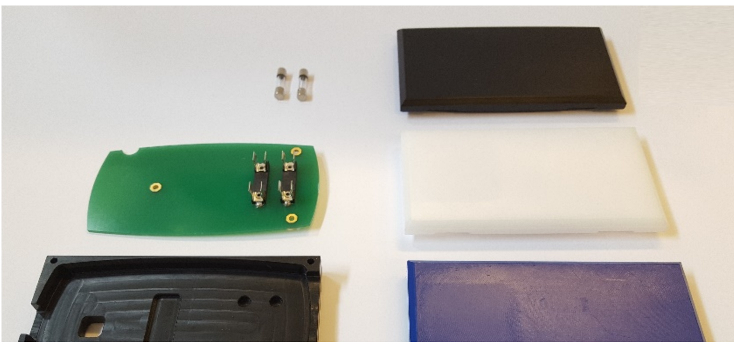

Fig. 2. The product manufactured by the AAU Learning Factory

The manufacturing system is controlled by MES, provided by Festo, named Festo MES 4, which is based on a local relational database. In real life settings, a configuration would often be transferred to an ERP system, and then possibly to a MES. However, in the current lab settings, and ERP system is not part of the setup, and thus the data is transferred directly from the configurator to the MES.

In order to demonstrate that products can be configured and then produced without manual operations, an integration was necessary between the two systems, the runtime configurator and the MES. No standard interfaces however existed which would provide this integration, so a custom interface was implemented. The interface was

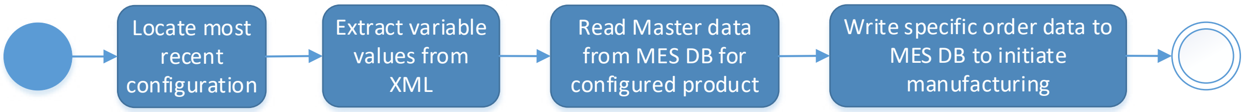


Fig. 3 The process implemented for transferring configurations from configurator to MES

implemented using Microsoft .NET Framework, as a windows application running locally on the MES server. The sequence of operations performed by the interface is shown in fig. 1.

When the user pushes a button in the user interface, the application queries the local file system for the most recent configuration file, which the application assumes is the configuration the user wishes to transfer to the MES. Prior to this, the user must save the configuration in the configurator runtime environment. Once the file is located, the application uses an XPath query to identify the variable, which holds the item number for the configured product, after which the value of this variable is retrieved. In Festo MES 4, products are added to an order by creating order lines (referred to as order positions in Festo MES4), and copying master data regarding the specific operations that are necessary to manufacture a specific product to an order specific table containing pending operations for the manufacturing system. This master data is retrieved from the MES based on the configured item number, and then written to the order specific pending operations table in the MES database. Once order data has been written and master data has been copied, and the order is marked as “Enabled” in the order table, the MES recognizes the new order and initiates manufacturing as soon as possible. In total four tables need to be manipulated to create the order, th “tblOrder” table containing order information, the “tblOrderPos”, containing the individual products in the order, “tblStep” containing the individual operations needed to manufacture the configured product, and “tblStepParameter” containing parameters for each operation that need to be passed to the PLCs in the manufacturing system.

As indicated above, the mapping between the configurator and the MES is done by using item numbers. Hence, in this setup, only products which have been created in the MES system can be configured and produced, which does not allow the same flexibility as a free configuration would have. However, this restriction is due to the way the MES works internally. The MES currently has 11 product variants defined, whereas the number of physically producible variants would be 816.

## 3. Learning Approach

The course, which is currently applying the AAU Learning Factory, and the configurator setup, is a course on master's level with the title "Flexible Manufacturing". The aim of the course is to provide the students with state of the art knowledge, skills and competences within mass customization and industry 4.0 within the business model domain, and modular and platform based product development and product configuration, and finally manufacturing system design based on changeability and reconfigurability concepts. Furthermore, the students learn the synergies and constraints between these domains as illustrated in figure 4.

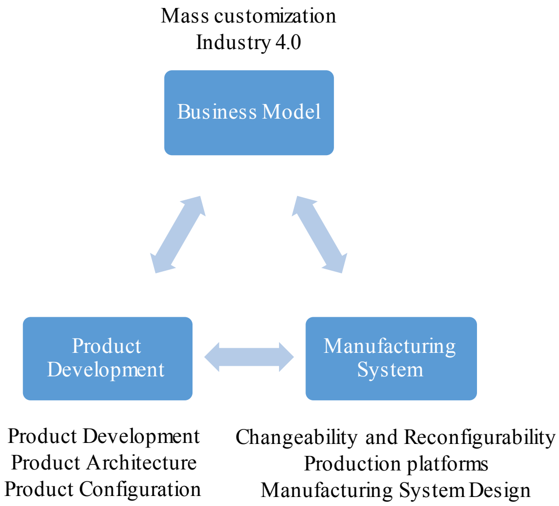


Fig. 4 Elements of the current course at AAU

The course applies a blended, problem based learning approach, implying that all lectures are combined with exercises, either case based or lab based where applicable. The course emphasizes all exercises are done in groups of 4-6 students.

In two lectures, which equals one whole day of student-teacher interaction, not including student self-study and preparations, the students work on product family modelling and development of product configurators. The learning objectives for this part of the course are to understand product family modelling and be able to model a range of products as the basis for developing product configurators. Secondly it is to structure a product configurator, so that it will provide a manufacturing cost or sales price, and provide data necessary for manufacturing the product.

The students are provided with literature on beforehand describing the background as well as specific methods. Furthermore, they are given short lectures by a teacher, elaborating and exemplifying the concepts from the provided literature. Once the lectures are finished, the students do lab exercises, outlined below, in groups.

- The students are given a tour of the lab manufacturing system, where they are introduced to the individual manufacturing processes, and the constraints they imply. Furthermore, they are introduced to the products, and given the physical components of the products, for doing the analysis of the product variety.
- The students are asked to do a product family model, representing the product variety, from a product side perspective, i.e. which variants would be possible from product constraint perspective, thus not taking into account what the MES currently supports. Furthermore, based on the MES database, they are asked to model also the variety, which is represented in the current MES data. Students are free to choose modelling methods; however, they are introduced to the product variant master [9] and class diagrams from the Unified Modelling Language.
- In a plenary session, each group presents their product family models for each other which typically reveals differences in the modelling approach and perception of the product variety. As an outcome the students learn both the technique for modelling product families, but also that given the same method, and same data foundation, different outcomes may be produced by different people based on their perception or preferences.
- The students are then introduced to the Configit Model tool, where they after a one hour introduction are able to do basic modelling. The students are introduced to the configurator-MES transfer interface, and the

requirements for the product configurator, in order for the interface to work. The groups are asked to each develop a product configurator, which is based on the product family model produced in the previous exercise.

- A plenary lab session is organized where the groups each test their product configurator on the MES server, by configuring a number of product variants, which are transferred to the MES and physically produced. This requires the students to adhere to the specifications for the interface, in practice meaning that there must be a variable in the configuration model with a specific name containing the item number of the configured product.
- The students are asked to discuss which would be the best approach if the system was to be expanded to cover all 816, theoretically possible variants rather than the current 11 in the MES database. This requires the students to consider whether to predefine all 816 variants with specific item numbers in the MES system or generate lists of operations dynamically, which is a typical dilemma in real life configuration projects.

## 4. Conclusion

The activities outlined in this paper introduces engineering master students to concepts of product family modelling and development of product configurators. Different from traditional, and previous years of doing this course, the students are given physical product to model and configure, and an interface to a lab manufacturing system is provided. Using this, students can test their product models and product configurators, by connecting their configurators to the manufacturing execution system, controlling the manufacturing system, and be able to manufacture the products they are able to configure using their configurators. Previously, the students would be asked to do modelling of a fictional product or a product from a commercial website and do a stand-alone configurator for this. Using the new approach, students are likely to be more engaged and learn more deeply, because the products are being manufactured. Also, the students learn more about the challenges of systems integration, and the considerations regarding placement of data and data redundancy, which are included as an objective of the students semester theme in the study programme.

The course receives consistently excellent feedback, and the knowledge, skills and competences, are regularly applied by students in projects with companies, indicating that the learning of the topic itself and learning the ability to apply the learnings in new contexts have been successful.

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